Approximate reasoning and Fuzzy Control

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SYNOPSIS

During the past several years fuzzy logic control (FLC) has been extensively studied by researchers[1, 3, 8, 9, 10, 12, 13]. Since it is close to human intuition, it is easy to learn and easy to apply. For this reason, it has been successfully applied to a wide variety of industrial processes and consumer products such as chemical reactors, cement kilns, vacuum cleaners, washing machines, auto focusing cameras, air-conditioners, robots, voice-controlled robot helicopters, elevator systems.

In its present form, fuzzy control can be considered as a special application of the theory of approximate reasoning. Accordingly, **this thesis attempts to analyze approximate reasoning and show that this methodology aims at modeling human reasoning, the constituent part of which is logic and the logical approach plays an important role in its application to fuzzy control**. It is hoped that **a formal logic description makes it possible to express and explain approximate reasoning and fuzzy control in a better way and offer a powerful tool to grasp the problem as well as to develop it further.**

Research in artificial intelligence has shown that a great deal of commonsense reasoning is behind humans' intelligent behavior. It is also well established that most of commonsense reasoning is approximate in nature. As commonsense knowledge is expressed using natural language, such description may not always of either black or white type and, hence, fall outside the domain of classical logic. Traditional mathematical models are found to be inadequate in representing commonsense knowledge. Multi-valued logics are found to be insufficient as possible truth values of sentences expressing commonsense knowledge are qualitative rather than quantitative in nature and possibly infinite in number. This motivated Zadeh to consider fuzzy logic — an infinitely many valued logic, and the theory of fuzzy sets in dealing with problems of human reasoning.

It has been observed that fuzzy set theory is based on the fuzzification of the predicate 'belongs to' or 'element of'. Accordingly, the concept of membership is considered as fundamental. This thesis attempts to explore the connection between indistinguishability modelled by fuzzy sets. As a possible formalization of indistinguishability it is proposed to study fuzzy equivalence or equility relation. It is also proposed that a suitable fuzzy equivalence relation can be derived from a given collection of fuzzy sets, which cannot be overcome by usual approximate reasoning schemes [6, 7].

Fuzzy logic is viewed as a unifing theory capable of explaining other approaches and gives understandable insight into the problem of approximate reasoning. This thesis propose to present control problem in which the logical aspect may give an interesting insight. In fact, this work attempts to formulate the logical principle of fuzzy control in a general way. Two major problems associated with existing literature are fuzzification and defuzzification procedures. It is proposed that these procedures be studied in the light of similarity relation.

Reasoning is a mental activity — actually a combination of intellectual activities — which allow the passage from a set of propositions, stated as premises, to a further proposition, taken as the conclusion or consequence, by virtue of a logical connection, with some degree of strength that link the conclusion to the premises. Taking a decision amounts to giving reasons and hence reasoning is an essential activity in decision-making. Reasoning is approximate when some of the propositions are imprecise in nature.

Zadeh first formulated the basic principles of approximate reasoning[16] considered to be a framework to study the remarkable human ability to understand natural language. Approximate reasoning is considered to be a powerful tool to study the remarkable human ability to understand real-world activities in terms of computational entities. It is defined as the process by which an imprecise/inexact/incomplete statement can be deduced from a set of possibly imprecise information. Since its inception, significant theoretical and practical advances have established approximate reasoning as an important field of research.

Now since imprecision is intrinsic in natural language, therefore, only in approximate characterization of the values of the variables are possible. In this regard, the concept of linguistic variable plays an important role. It is a tool for approximate characterization of the values of variables and their interrelation[17].

Different forms of approximate reasoning have been described by many researchers since then[2, 4, 5, 16, 18]. Zadeh's concept of approximate reasoning is based on the assumption that the imprecision in natural language is possibilistic in nature — when meaning is the concern. Possibility theory plays an important role in translating natural language expression into possibility distributions to which the rules of inference can be applied for a possible conclusion.

The main **motivation** of the theory of approximate reasoning is the desire to build up a quantitative framework that will allow us to derive an approximate conclusion from imprecise knowledge. Approximate reasoning is somewhat structured and reliable yet flexible. Different patterns of approximate reasoning in human beings indicate a need for similarity matching, in situations, where there is no directly applicable knowledge, to come up with a plausible conclusion. In such cases, the confidence in a conclusion may be determined, based on a degree of similarity. Similarity enables us to use background knowledge in order to recognize how a new case is like an old one. In order to capture this we also need corresponding flexibility in our model. Specifically, in deriving a consequence we need means to handle gradual information on the one hand and the concept of similarity on the other hand. This project propose to study the concept of similarity in detail and its incorporation in approximate reasoning at different level.

The **significance of the study is considerable**. Approximate reasoning is considered to be a powerful tool to understand real-world activities in terms of com-

putational entities. It has been found that the concept of similarity is inherent in approximate reasoning and cannot be avoided. Similarity based approximate reasoning may be applied in wide and challenging fields of investigations. The reasoning mechanism in it includes the compositional rule of inference due to Zadeh as a special case. There is evidence to show that even Turksen's similarity based reasoning is also included as a special case of the proposed similarity based approximate reasoning. Similarity based approximate reasoning plays an important role in modeling complex and highly non-linear physical systems capturing human's expertized knowledge and dealing with the linguistic uncertainty associated with it[11].

A thorough exposition of inferring in approximate reasoning is to be studied. In the process, an adequate review of a collection of well-used terms needed for a comprehensive understanding of the methodology of approximate reasoning will be made. The focus will first be on fuzzy set theoretic approach to inference in approximate reasoning. A possibilistic approach as well as an information theoretic approach to approximate reasoning will also be studied. Different models of reasoning — rule-based and resolution-based, ordinary, extended and the applicable forms are to be examined thoroughly. A new model of rule-based approximate reasoning is to be probed. In order to provide a better understanding of the semantics of approximate reasoning methodology, a pictorial description of the different operations underlying conventional approximate reasoning is to be presented by considering typical problems.

The concept of similarity index for measuring the nearness of fuzzy sets over a given universe is to be analyzed. Different approaches for a solution to the problem viz., cardinality consideration, sub-sethood consideration need to be discussed. As it is proposed to use such an index in modifying a fuzzy set/ fuzzy relation, a point wise comparison of the membership values of elements underlying the sets is to be considered as a special case. A brief review of the existing measures is to be presented[14, 15]. New methods will then be presented, based on some basic properties of similarity. Results are to be extensively discussed. Based on these properties it is hoped to propose a set of axioms for defining a similarity index between two fuzzy sets. This will certainly make the task of choosing a particular measure for use, easier. A methodological note is in order here: in describing different similarity measures, it is assumed that the universe of discourse is finite. Similarity measures for infinite fuzzy sets too are to be considered.

It is proposed to study a step-by-step introduction of the similarity measure [19] into approximate reasoning methodology. Different existing approaches to similarity based reasoning are to be considered and then a new mechanism of approximate reasoning based on similarity measures is to be developed. Existing similarity based approach as also an ordinary approximate reasoning mechanism for deriving a consequence are to be combined together in order to develop an effective mechanism. A fuzzy relation will first be constructed from the translation of the conditional statement. A thorough exposition on the use of different translating rules is to be

made. The mechanism should be such that every change in the concept as appears in the conditional (general) statement and that in the fact, is to be incorporated in the fuzzy relation between the variables defining the condition. This procedure ensures the inference as a function of the concerned change. The more the change, the less specific should be the conclusion. For that, it is proposed to formulate different schema for the modification of the conditional fuzzy relation. Another point to be considered is how to avoid the use of certainty factor concept for rule-firing. To do that it is proposed to modify the inference mechanism in such a way that a significant change will make the conclusion less specific. This can be done if an expansion type of inference scheme is chosen. Here, the 'UNKNOWN' case may be taken as the threshold. Explicitly, when the similarity value becomes low, i.e., when the change is significant, the reasoning process is such that the inference becomes unknown. At the same time, when there is no change, i.e., a perfectly matching case, it is possible to derive the expected consequence (the consequence of the condition in a rule-based system). In other cases, the consequence should be no better than what the condition allows. Different interesting results in this direction are to be extensively discussed. It is expected to show that the concept of specificity measure of fuzzy sets is inherent in such similarity based approximate reasoning methodology. Examples are to be considered to demonstrate the computations under the procedure. In order to generate some 'feeling' about the proposed similarity based approximate reasoning, this thesis will try and present interpretations through pictorial representation wherever possible. It is proposed to compare the result of this new method with results of other existing approaches to similarity based reasoning method and Zadeh's compositional rule of inference. In the process, it is expected to formulate different models for similarity based approximate reasoning rule-based as also resolution-based, ordinary, extended and applicable forms.

Efficiency of implementation of the proposed method of similarity based approximate reasoning is to be measured by considering application of the same in the design of rule-based fuzzy control. As there is no generally applicable semantic methodology for the construction of fuzzy controllers for different industrial applications that is guaranteed to result in a high performance closed-loop control system it is proposed to **design fuzzy controllers for a variety of applications in a series of case-studies**. Fuzzification and defuzzification, two basic operations, used in the development of fuzzy systems is to be extensively discussed in the light of fuzzy logic based new approximate reasoning mechanism. New schema for fuzzification and defuzzification, suitable for similarity based approximate reasoning, are to be incorporated in the inference unit. These methods are to be used in problems of process control. Simulations are to be performed with some real data. Results are to be tabulated along with their interpretations. Further possibilities of the use of fuzzy logic and similarity based approximate reasoning in other emerging areas of research is to be explored.

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